WASHINGTON STATE
DEPARTMENT OF
ECOLOGY

Periodic Dam Safety Inspection Report

Serenity Lake Dam

September 2001
Pub. No. 01-11-014

printed on recycled paper

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Serenity Lake Dam

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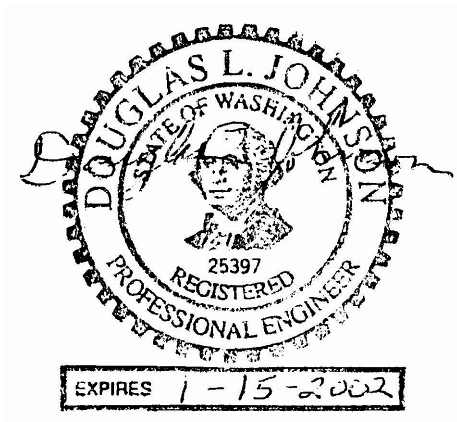
Periodic Inspection Report

Water Resources Program
Report 01-11-014

The dam safety inspection of the Serenity Lake Dam, and the engineering analyses and technical material presented in this report were prepared under the supervision and direction of the undersigned professional engineers, in accordance with RCW 43.21A.064(2).



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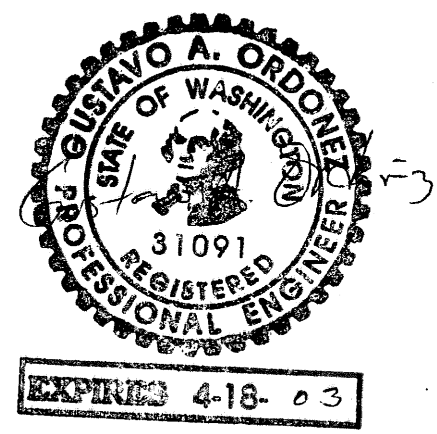

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SERENITY LAKE DAM
Periodic Inspection Report

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1. Introduction

Under state law (RCW 43.21A.064(2)), the Department of Ecology has responsibility and authority to inspect the construction of all dams and other works related to the use of water, and to require necessary changes in construction or maintenance to reasonably secure safety to life and property. This report has been prepared in accordance with this statute.

The report presents the results of the first periodic inspection and safety evaluation of the Serenity Lake Dam by the Ecology Dam Safety Office (DSO). The report provides:

- Background information,
- A description of the project,
- Results of the October 17, 2000 inspection,
- Engineering evaluation and analyses of the design of the project,
- Required remedial actions based on the findings from the current inspection.

2. Background Information on the Project

Serenity Lake is a recreational reservoir, located about 5 miles southeast of the city of Chewelah in Stevens County (Figures 1 and 2). The reservoir is impounded behind a 12-foot high earthfill dam, which is owned and operated by Stan & Sandra Long. The project lies on a small, unnamed ephemeral stream, which discharges through springs into Bulldog Creek, which in turn discharges into the Colville River. The reservoir is primarily filled by runoff from the surrounding 5.1 square mile watershed.

According to DSO files, the dam was originally constructed by James E. Keeley, and was named Jumpoff Jim Reservoir Dam. The purpose of the reservoir was originally fish propagation and recreation, which was later amended to include irrigation. The dam was designed by Clearwater Construction and Engineering of Lewiston Idaho in 1971. According to the construction plans approved by the Department of Ecology, the dam was to be a homogeneous earthfill embankment with a height of 12 feet, which would impound a 19 acre lake with a storage capacity of 115 acre-feet. As discovered during this inspection, the actual lake has a surface area of 28 acres and impounds over 150 acre-feet. The principal spillway for the dam was to be a 12-inch drop-inlet “trickle-tube”, and the emergency spillway was to be a 10 foot wide open channel around the left abutment. Sometime during construction, the emergency spillway was changed to a 36-inch CMP. The dam was completed in 1972 and was filled that year. In 1980, the Longs acquired ownership of the dam from Mr. Keeley.

On July 15, 1999, the DSO performed an inspection of the dam, in order to assess its condition and the downstream hazard potential in the event of a failure. This inspection revealed that the dam appeared to be fairly well built, but maintenance of the facility was lacking. In addition, at least one home had been built in the valley downstream from the dam since it was built. Thus, it was decided that the dam should receive a Class 1 inspection, to more thoroughly assess the hazard potential and to investigate what repairs might be needed to meet modern dam safety standards. This report describes the Class 1 inspection and findings.

3. Field Inspection of the Facility

The field inspection of the Serenity Lake Dam was performed on October 17, 2000. The Dam Safety inspection team consisted of the following personnel:

Name	Aspects Covered
Douglas L. Johnson, P.E.	Coordinator, Hydrology/Hydraulics
Gustavo Ordonez, P.E.	Geotechnical
Guy Hoyle-Dodson, P.E.	Hydrology/Hydraulics

Sandra and Stan Long were present during the inspection and provided information on their knowledge of the dam as well as current operation and maintenance procedures.

3.1 Reservoir

Serenity Lake has a surface area of 28 acres at the normal pool elevation of 2140.7 feet[a]. The reservoir impounds about 168 acre-feet at normal high pool, and can impound approximately 185 acre-feet at the current dam crest elevation of 2142.2 feet. The reservoir is primarily filled by runoff from a small creek that drains the watershed, and by springs.

At the time of the inspection, the reservoir level was at elevation 2140.45 feet, which was 0.07 feet below the CMP spillway invert, and 1.75 feet below the dam crest level. However, the reservoir appeared to have recently been drawn down a few inches using the low level outlet, which was open at the time of our inspection. Normally, the 36-inch CMP controls the lake level, with a maximum pool elevation of 2140.7 feet, only 1.5 feet below the dam crest. This differs from the approved plans, which called for a maximum pool elevation of 2139.4 feet and a dam crest elevation of 2143.0 feet, providing 3.4 feet of freeboard.

The slopes on both sides of the reservoir were examined from the dam during the inspection. The slopes immediately surrounding the reservoir are moderate, so the chances of a landslide generating waves that could affect the dam appeared unlikely.

[a] All elevations in this report are based on an assumed local project datum of 2130.5 feet at the invert of the low level outlet conduit.

3.2 Embankment, Abutments and Foundation

Serenity Lake Dam is a zoned earthfill embankment with a height of 12 feet, a crest width of 15 feet, and a crest length of 590 feet. The dam was provided with a central "clay" core and upstream impervious foundation blanket, and a 4-foot deep cutoff trench to reduce seepage. A survey of the dam during our inspection revealed the crest elevation varies from 2142.2 feet near the spillway, to 2143.3 feet near the right (north) abutment. (Figure 3). This differs significantly from the crest elevation of 2143.0 feet shown on the 1972 plans. It is not known whether this discrepancy is due to settlement of the embankment or a result of improper grading during construction. The upstream slope is inclined at about 3H:1V, while the downstream slope is much flatter, at 5H:1V. The flatter downstream slope was provided so that "dam will blend with existing ground on downstream side".

We first inspected the visible portion of the upstream slope above the water line. Only a small portion of the upstream slope was visible above the water line. No signs of cracking, instability or erosion were noted in this area. Wave erosion had cut into the slope and created a vertical scarp at the water line. We suggested that improved slope protection may be needed here.

We next examined the dam crest, and discovered no cracks, sinkholes, erosion, or other signs of instability. Our survey of the dam crest showed that most of the dam crest was below the design elevation of 2143 feet. This has resulted in only 1.5 feet of freeboard instead of the 3.4 feet shown on the dam plans. Several animal burrows were noted crossing the crest, which could pass water if the pool rises to a few inches below the crest. We informed the Longs that these burrows needed to be filled in.

An examination of the downstream face of the dam revealed that there was no sign of cracking, sinkholes, settlement, or other instability. No seepage or wet areas were found on the downstream face or the foundation area. The only deficiency noted was animal burrows in numerous locations. These burrows likewise need to be filled in.

3.3 Principal Spillway

The principal spillway for the Serenity Dam is a 12-inch diameter drop inlet spillway located near the midpoint of the embankment. The original plans show that the vertical riser was originally open and had a crest elevation of 2139.4 feet. However, during our inspection we discovered that the riser has been covered by a steel plate, and it no longer functions as the lake level control. The drop inlet now functions only when the control valve at the base of the riser is opened. As a result, the CMP emergency spillway functions as the lake control, with the lake level at about Elevation 2140.7 feet. Coupled with the lower dam crest, this has reduced the normal freeboard from 3.6 feet to only 1.5 feet. This has also greatly reduced the ability of the dam to handle floods, and increased the chances of an overtopping failure. In addition, the dam is now storing more water than allowed by the water right certificate and reservoir storage permit. This situation needs to be rectified in the short term by either removing the cover or opening the outlet valve to lower the lake level to 2139.5 or lower. In the longer term, a safe freeboard level can be set as part of the spillway modifications discussed in Section 4.5

3.4 Outlet Works

The low level outlet works at Serenity Lake Dam are part of the drop-inlet spillway structure. A gate valve is attached to the base of the vertical riser, which discharges into the 12-inch discharge pipe. This pipe carries flows through the dam and discharges at the downstream toe.

At the time of our inspection, the gate valve was partially open and the outlet was discharging about 0.5 cubic feet per second. Since the lake was full, we were only able to examine the downstream end of the 12-inch discharge pipe. The CMP was in fairly good condition, with only some minor rusting of the exposed portion noted. No seepage was noted from the embankment surrounding the pipe. The pipe discharges into a rock-lined pool at the downstream toe. No erosion damage or other problems were noted in this area.

3.5 Emergency Spillway

The emergency spillway for Serenity Lake Dam is located at the left (south) end of the dam, and consists of a 36-inch diameter CMP through the dam, with a half-round CMP flume on the downstream slope. This spillway differs from the 10-foot wide open channel spillway shown on the approved plans. This change was apparently made during the original construction of the dam, based on as-built plans in Department of Ecology files. The invert of the CMP is at 2140.5 feet, only 1.7 feet below the dam crest level. This differs from the original plans, which called for the emergency spillway channel to be at elevation 2139.5 feet. Since the drop inlet spillway is not functional, the emergency spillway has been functioning as the main spillway and has resulted in raising the normal lake level to about 2140.7 feet. This has also resulted in a significant reduction in the ability of the dam to withstand floods, as the discharge capacity of the 36-inch CMP is much smaller than the original 10-foot wide open channel.

Our inspection of the emergency spillway showed the CMP to be in good condition, with no significant rust or corrosion noted. The logs and debris present during our last inspection had been cleared from the pipe and half-round flume. The flume was in somewhat worse condition than the pipe, with rust and corrosion noted on the invert, but it was still serviceable.

4. Evaluation and Analyses

4.1 Downstream Hazard Classification

It is common practice to use a classification system to describe the general level of development downstream from a dam, which could be affected by a flood should the dam fail. This classification is used for selecting minimum design levels for the various elements of the facility, such as the flood used to design or analyze the spillway(s). Table 1 below lists the classification system used by the Dam Safety Office.

Table 1. Downstream Hazard Classification

Downstream Hazard Potential	Downstream Hazard Classification	Column 1A Population at Risk	Column 1B Economic Loss Generic Descriptions	Column 1C Environmental Damages
Low	3	0	Minimal. No inhabited structures. Limited agriculture development.	No deleterious materials in water
Significant	2	1 to 6	Appreciable. 1 or 2 inhabited structures. Notable agriculture or work sites. Secondary highway and/or rail lines.	Limited water quality degradation from reservoir contents.
High	1C	7 to 30	Major. 3 to 10 inhabited structures. Low density suburban area with some industry and work sites. Primary highways and rail lines.	Severe water quality degradation potential from reservoir contents and long-term effects on life.
High	1B	31-300	Extreme. 11 to 100 inhabited structures. Medium density suburban or urban area with associated industry, property and transportation features.	
High	1A	More than 300	Extreme. More than 100 inhabited structures. Highly developed densely populated suburban or urban area.	

Prior to the 2000 inspection, the setting downstream from the Serenity Lake Dam was classified as having a Hazard Class of 2, if a dam failure should occur. As part of the inspection, the downstream hazard potential was reassessed. Downstream from Serenity Lake Dam, the creek flows about 2 miles down to the 20-foot high roadfill for Highway 395. One home is located along the creek in this reach. At Highway 395, the only outlet under the roadfill to drain the upper basin is a 36-inch culvert. Due to the limited capacity of this culvert, large floods would back up behind the roadfill. A dam break flood on top of a natural flood could cause this roadfill to fail. Downstream from Highway 395, the creek flows into the headwaters of Bulldog Creek. Ten more homes are located between Bulldog Creek and the Colville River that could be affected should the Highway 395 roadfill fail. Based on this setting, we decided to perform a more detailed dam break analysis.

4.1.2 Dam Break Analysis

First, the failure of Serenity Lake Dam was simulated using the US Army Corps of Engineers HEC-1 computer model. Input parameters for computing the dam breach were based on procedures contained in Technical Note 1 – Dam Safety Guidelines[1]. The breach parameters for Serenity Lake included a base width of 40 feet, side slopes of 1H:1V and a time to failure of 30 minutes. The dam break discharge at Serenity Dam was computed for a failure during a 500-year flood of 90 cubic feet per second (cfs) on the watershed, with the lake level at the emergency spillway invert at the time of failure. (This flood was selected because it is the minimum design flood for any dam in Washington State, and the lake would be overtopping the dam crest level prior to failure.) Using these parameters, the dam break peak discharge was computed to be 4216 cfs, which is over 46 times larger than the 500-year flood. The total volume released by the dam break was over 190 acre-feet of water.

The dam break flood was then routed downstream to the US Highway 395 roadfill using the Muskingum Routing routine in the HEC-1 model. (*More detailed flood routing was not considered necessary here, as the only home in this reach would not be inundated initially by the dam break flood, but would be flooded by backwater behind the Highway 395 roadfill*.) The dam break flood was then routed through the roadfill, modeling it as a dam and reservoir. The elevation-storage capacity curve was developed using USGS topographic maps and DSO survey data. The maximum storage capacity behind the roadfill before it begins to overtop the right abutment (at Elev. 2059.0 feet) was estimated to be 350 acre-feet. Since the 500-year flood was already occurring, the limited capacity of the culvert resulted in the roadfill already being surcharged to within 4 feet of the abutment prior to arrival of the dam break flood. The dam break flood would exceed the remaining storage capacity and would overtop the right abutment by 1.3 feet. This would send most of the overtopping flow of 360 cfs down Highway 395 to the north, toward a large natural depression. However, some flow would pass over the top of the roadfill into the creek channel below. It is quite possible that the Highway 395 roadfill would fail under this loading, by piping, since the roadfill wasn't designed as an impounding barrier. If the roadfill fails, the HEC-1 model estimated the peak discharge at nearly 6,700 cfs. The detailed flood routing was not carried beyond the Highway 395 roadfill. Clearly, by inspection, a flood of this magnitude would overwhelm Bulldog Creek and destroy the 10 homes located there.

Based on these findings, a total of 11 homes are potentially at risk from a failure of Serenity Lake Dam. In addition, the dam break flood could wash out a major state highway, and cause another small dam to fail. Therefore, the hazard classification for the Serenity Lake Dam should be upgraded to **Hazard Class 1B, *High*** Downstream Hazard. An Inundation Map showing the property at risk is shown in Figure 4.

4.2 Hydrology and Spillway Adequacy

As part of this inspection, a hydrologic analysis was performed to assess the adequacy of the project's spillway. A summary of that analysis is provided in the following sections.

4.2.1 Hydrologic Characteristics of the Watershed

Based on 65 years of record at the Deer Park Weather Station, and on isopluvial maps of Washington State prepared by the US Weather Bureau, the mean annual precipitation for the Serenity Lake basin is about 22 inches. The season distribution is such that about 68% of the annual precipitation falls between October and March. Much of this precipitation falls as snow, and results in a winter snowpack that typically reaches a maximum in January or February. Historically, the greatest 24-hour precipitation amounts observed in the region around Serenity Lake have generally occurred between November and March. The greatest 24-hour storm measured at a nearby weather station was 2.35 inches at Chewelah in May 1998. Other large general storm events in the area have included 1.96 inches in 24 hours and 3.1 inches in 72 hours at Chewelah in November 1973, and 1.97 inches in 24 hours at Deer Park in December 1966.

Generally, three types of flood events can occur in Eastern Washington. The first type is a combined rain and snowmelt event, occurring in winter or early spring. The second type is a snowmelt flood, which occurs every spring in response to seasonal warming. The third type is a thunderstorm flood event, which occurs in response to intense rainfall during spring or summer thunderstorms. Runoff in the area around Serenity Lake is relatively small, due to the semi-arid climate and high infiltration rates of the soils. This is evidenced by the small size of the stream channel in relation to the basin size, and the fact that the stream "sinks" and runs underground downstream from Highway 395. However, if a storm is sufficiently large, the precipitation intensity can exceed the infiltration capacity of the soils, resulting in significant overland flow or "flash floods". These floods are quite rare, as they occur only once or twice in a lifetime, but when they do occur, their results can be devastating.

4.2.2 Assessment of Existing Spillway Adequacy

Based on the relatively large drainage basin above the dam (5.1 mi^2), the lack of freeboard, and the limited spillway capacity provided by the 36-inch CMP, it appeared likely that the dam would not be capable of meeting current dam safety standards for spillway design. Thus an analysis was performed to estimate the recurrence interval of the flood corresponding to the capacity of the existing spillway. The first step in this analysis was to estimate the flood peak discharge for the 10, 25, 50 and 100 year events, using USGS Water Resources Investigations Report 97-4277, *Magnitude and Frequency of Floods in Washington*[2]. This report uses regression equations which utilize flood data from streamflow records on similar watershed in Washington State. Using parameters appropriate for the region, the flood peak discharges were computed and are shown in Table 2.

Table 2 – Flood Peak Estimates vs. Spillway Capacity

Spillway Capacity	COMPUTED FLOOD PEAK DISCHARGE				
	5-year	**10-year**	**25-year**	**50-year**	**100-year**
17 cfs*	20 cfs	28 cfs	42 cfs	51 cfs	62 cfs

*Includes 3 cfs max from low level outlet.

Comparing the flood peak flows with the computed discharge capacity of the spillway and outlet, it can be seen that Serenity Lake Dam can only handle about a 5-year event without significant overtopping. This means that in any given year, the dam has a 20% chance of overtopping. This is grossly deficient spillway capacity for any dam, much less a dam with a high downstream hazard potential. Thus the spillway capacity at this dam is inadequate, and modifications are needed to meet state standards for spillway design.

4.2.3 Selection of Design Storm

Since the previous section revealed that the dam has inadequate spillway capacity, additional capacity is needed so large floods can safely be discharged, rather than lead to dam failure from overtopping of the embankment. Thus, a sufficiently large inflow design flood (IDF) must be selected, commensurate with the downstream hazard, for sizing and upgrading the spillway.

The first step in the IDF analysis was to select a design storm appropriate for the level and type of development downstream from the dam. The DSO uses design storm selection criteria[3] that have an eight-step format. Design storms range from a minimum of a 500-year storm (Step 1) to the Probable Maximum Precipitation (Step 8). Based on the extreme consequences of a dam failure including loss of lives described in Section 4.1.1, the Dam Safety Guidelines require that the dam be capable of passing a Design Step 3 event. A Step 3 storm has about a 1.5% chance of being exceeded in a 50-year period. Therefore, a Design Step 3 storm was used to determine the IDF.

The type of storm selected for analyzing the Serenity Lake Dam and spillway was a long duration, rain on snow event, as discussed in Section 4.2.1. This type of storm produces a flood having a moderately large flood peak and a large runoff volume. This storm is critical for this basin, because the flood storage available in the Serenity Reservoir is fairly large in relation to the size of the watershed. The Step 3 design general storm has a 24-hour depth of 4.5 inches and a 72-hour depth of 6.2 inches. This storm is about twice as large as the 100-year event. Estimates of the precipitation amounts were made using data contained in NOAA Atlas 2[4] and analyses of extreme storms in the region[5]. The temporal distribution of the design storm was developed based on the Washington Dam Safety Guidelines, Technical Note 3[6], using the 50% exceedance hyetograph.

4.2.4 Rainfall-Runoff Model

The hydrologic analysis performed by the DSO utilized the U.S. Army Corps of Engineers HEC-1 program, to analyze the runoff characteristics of the basin for the design storm. HEC-1 is a single event model capable of simulating direct runoff from the land surface, channel routing in the creeks, as well as reservoir elevations and discharges. Inputs to the HEC-1 model include precipitation, land cover, soil types, and hydraulic characteristics of the reservoir. Input data necessary for computing the floods produced by rainfall events is summarized below.

A major limitation with HEC-1 is that it cannot simulate subsurface discharge to creeks or reservoirs. All precipitation that infiltrates is assumed lost from the system. This limitation is a problem for basins such as Serenity Lake, because the infiltration capacity of the soil is quite high in relation to the rainfall intensities. A modeling scheme was developed for use with the 72-hour storm that approximates a subsurface flow component for the infiltrated precipitation. This scheme is detailed later in this report.

Drainage Basin – The drainage basin above Serenity Lake Dam has a total area of 5.08 square miles (Figure 5). The basin is largely forested with Ponderosa pine. Basin elevations range from 2260 feet at the dam to over 3200 feet at the southern boundary. The Beity Lake Dam is located upstream from Serenity Lake and was included in the computer modeling. For purposes of runoff modeling, the watershed was divided into three subbasins, the Beitey Lake watershed, the water shed between Beitey Lake and Serenity Lake, and the lake itself.

Soils and Infiltration - Based on USDA Soil Conservation Service soils mapping[7] of the area, the soils in the basin consist predominately of loams and silt loams from the Aits, Bonner, Huckleberry, and Raisio soil groups. The SCS lists the permeability of these soils to be 0.6 to 2.0 inches/hour, and classifies them in hydrologic soil groups B and C. Bedrock and glacial till underlies these soils at depths ranging from 30 to 60 inches. Based on the preceding information and on calibration runs performed for a hydrologic analysis of Beitey Lake Dam[8], a uniform infiltration rate of 0.50 in/hr was used for the upper soil layer, and a deep percolation rate of 0.07 in/hr was used for the bedrock/till layer, with an initial loss of 1.0 inches.

The high surface permeability of the soils indicates that very little, if any, surface runoff occurs from typical storm events, and shallow groundwater flow is likely the dominant runoff mechanism in the basin.

Unit Hydrographs - The Gamma Distribution[9] was used as the unit hydrograph for surface runoff. The flow peak and travel time were computed using methods derived by the USBR in Design of Small Dams[10] for the Coast & Cascade Ranges of Washington. The computed lag time for the basin was 65 minutes, and a 10-minute unit hydrograph was selected.

The Gamma Distribution was used for the subsurface hydrograph because it provides the flexibility needed to set the volume beneath the hydrograph peak as well as the time of the peak. This flexibility is necessary when simulating a subsurface response because subsurface hydrographs are attenuated and have a much longer duration compared to surface hydrographs. The lag times for the subsurface runoff component was set at 8 hours, based on computed time lags for basins in the Puget Sound lowlands[11] and on calibration runs. The unit hydrograph peak flow rate is defined by Equation 1, where k is the percent of the hydrograph discharge that occurs beneath the peak. For a subsurface response, a k value of 7.5 percent was used. This produces a unit hydrograph that has a ratio of recession to rise time of about three to one.

$$Q_p = \frac{1936kAR}{\mathrm{P_r}} \tag{1}$$

Where: **k** is the percent of hydrograph discharge, which occurs during the time increment $P_r/5$ of the flood peak.
P_r is the period of rise of the hydrograph (hours).
A is the watershed area, (square miles).
R is the volume of runoff, (inches).

Snowpack Data – Snow is common in the basin and the snowpack typically reaches a maximum in January or February. Based on information in the hydrologic analysis for nearby Power Lake Dam[12], a 5-year snow water content of 5.0 inches was assumed to be present during the design storm event. Temperature data at the Chewelah station from the January 14-16, 1974 storm and flood were used as input to model the snowmelt. The degree-day method of snowmelt was used, with a melt coefficient of 0.11. This resulted in a total snowmelt during the design storm of 3.6 inches.

4.2.5 Inflow Design Flood

The above parameters were used in the HEC-1 model to determine the Inflow Design Flood (IDF). The total inflow hydrograph (surface, interflow, and rainfall on the lake) is shown in Figure 6. The computed Step 3 IDF had a peak inflow of about 445 cubic feet per second (cfs), with a total runoff volume of 1260 acre-feet (4.7 inches) on the watershed.

4.2.6 Flood Routing through Reservoir and Spillway

To determine the response of the reservoir to floods, flood routing procedures were used in the HEC-1 model to determine the maximum lake elevation and spillway discharge. Reservoir routing of the IDF was performed using the as-built emergency spillway configuration. Spillway discharge capacity information is needed as part of the flood routing analysis for the facility. An elevation-discharge curve was computed for the existing spillway and the maximum discharge capacity was 14 cfs with the reservoir at top of dam level.

The initial reservoir elevation was set at 2140.6 feet, which is at the principal spillway invert elevation. This reservoir level is considered the normal maximum operating level. The flood routing revealed that the IDF greatly exceeded the capacity of the existing spillway, and would overtop the dam by one foot for several hours. Such a depth of overtopping would likely result in an erosive failure of the embankment. Based on the foregoing, with the present dam and spillway configuration, Serenity Lake Dam cannot safely accommodate the IDF. In fact, the analysis showed that the facility can presently only handle about 3% of the design flood.

4.2.7 Spillway Repair Options

Since the Inflow Design Flood discussed in the previous section overtops the dam, it is clear that modifications will be needed to increase the spillway capacity to pass the flood. Fortunately, the spillway deficiency at Serenity Lake Dam is relatively easy to rectify. Two options are proposed to increase the spillway capacity and freeboard to allow the dam to handle the design flood. These options are detailed as follows.

Option 1: Raise Dam 0.7 feet and add 60 foot wide emergency spillway – This option would involve adding fill to the dam to restore the crest elevation to 2143.0 feet, and lowering a 60 foot wide section of the dam near the right abutment to act as an emergency spillway. The lowered section would have an elevation of 2141.0 feet, 0.5 feet above the invert of the existing spillway pipe. Ideally, this area would be in native soil and would require only minor erosion protection. This option would allow the lake level to remain at its current elevation. Figure 7 provides a conceptual drawing of this repair scheme. With these modifications, the dam can handle the IDF with 0.3 feet of freeboard below the crest elevation. The advantage of this scheme is that it would be relatively easy and inexpensive to construct. The disadvantage is that the lake would continue impounding more water than allowed under the reservoir permit and water right certificate, and the owners would have to apply for a water rights change from the Dept. of Ecology.

Option 2: Reduce lake level, add 45 foot wide emergency spillway – This option would involve retaining the existing dam crest elevation, restoring the drop-inlet or lowering the 36-inch CMP to maintain normal lake elevation at 2139.5 feet, and lowering a 45 foot wide section of the dam crest to 2140.0 feet to act as an emergency spillway. Under this repair scheme, the dam could pass the flood with 0.2 feet of freeboard below the crest. However, if 3 short sections of the dam crest were filled in, the freeboard would increase to 0.4 feet. The advantage of this scheme is that the dam crest would not have to be raised, and the lake storage would be restored to the permitted volume of 115 acre-feet. The disadvantage would be the cost and difficulty of repairing the drop-inlet spillway or lowering the CMP spillway conduit.

4.3 Embankment Stability

As part of the inspection, the stability of the critical embankment section of Serenity Lake Dam was evaluated.

Static Stability - A static stability analysis was not performed for the dam cross-section. First, as a practical matter, such an analysis would require representative soil data on the embankment and foundation that presently, to our knowledge, do not exist. Second, and more importantly, the performance of the dam for the last 30 years has been good. The dam exhibits no signs of instability or seepage, and the broad crest width and 5:1 downstream slope minimize any concerns of a slope failure leading to a dam breach. Therefore, based on the forgoing, the static stability of the embankment is judged to be satisfactory.

Displacement Evaluation – Earthquakes generate motions within embankments that produce a lowering and lateral spreading of the dam cross section. The magnitude of these embankment movements is assessed with a displacement or Newmark analysis. In the case of Serenity Lake Dam, by inspection and based on Seed's studies[13] on the performance of dams during earthquakes, the silty loam nature of the embankment materials, and the static stability evaluation, the crest settlement predicted by a Newmark Analysis would only be a small fraction of the normal 1.7 feet of freeboard on the embankment. Thus, at present, no additional displacement analysis is considered necessary.

Liquefaction Evaluation – A liquefaction type failure of the embankment soils, by inspection, was considered to have a low likelihood of occurrence, because of the loamy nature of the embankment and foundation materials, the apparent density of the fill, and the unsaturated condition of the embankment materials.

Thus, based on the forgoing qualitative evaluations, the stability of the embankment is judged to be adequate.

4.4 Operation & Maintenance

The owner does not have a written Operation and Maintenance (O&M) Plan for Serenity Lake Dam. Operation of the dam involves opening the low level outlet to regulate lake level and outflow to meet the needs of fish and wildlife. Maintenance is performed on an as-needed basis, and primarily consists of removing debris from the spillway entrance and flume. Mr. And Mrs. Long live adjacent to the dam, and frequently inspect the facility for obvious deficiencies.

The lack of formal O&M procedures at the dam is of some concern. Furthermore, the Dam Safety Regulations require that an O&M Manual be prepared for a facility within 180 days following inspection by the Department of Ecology. Thus, a formal O&M Plan must be prepared for the dam, containing information on the regular operation, maintenance, inspection, and monitoring of the dams. Additional information on this requirement is provided in Ecology Publication No. 92-21, *Guidelines for Developing Dam Operation and Maintenance Manuals*.

3.5 Emergency Preparedness

At present, emergency preparedness at the Serenity Lake Dam is unsatisfactory. No Emergency Action Plan has been prepared for this facility, as was required following the 1999 DSO inspection.

The Dam Safety Office requires owners to develop and maintain an Emergency Action Plan for all dams located above populated areas. This plan must contain procedures for notifying downstream residents of an impending dam failure, as well as the specific circumstances under which a warning is issued, and actions to take in emergency situations to help prevent, or minimize the impacts of, a dam failure.

Considering the foregoing, an EAP needs to be written in accordance with the DSO guidelines and this report. Responsible parties need to be familiar with the plan, and aware of their responsibilities in an emergency. Information on EAP requirements is provided in Ecology Publication No. 92-22, *Guidelines for Developing Emergency Action Plans*.

5. Conclusions and Required Remedial Actions

Based on our inspection, the Serenity Lake Dam appeared to be fairly well constructed embankment. However, the spillway capacity at the dam is grossly inadequate, given the increased downstream hazard potential. This deficiency, along with the other needed corrective actions, are discussed as follows.

5.1 Increase Spillway Capacity at the Dam

As discussed previously in this report, Serenity Lake Dam does not have adequate spillway capacity for handling the Step 3 Inflow Design Flood event. In fact, the existing dam and spillway can only handle about a 5-year flood, which means there is a 20% chance of the dam being overtopped in any given year. Thus, modifications are clearly needed to increase the spillway capacity. Two possible options for the capacity increase were detailed in Section 4.2 and are summarized here:

Option 1: Raise Dam 0.7 feet and add 60 foot wide emergency spillway – This option would involve adding fill to the dam to restore the crest elevation to 2143.0 feet, and lowering a 60 foot wide section of the dam near the right abutment to act as an emergency spillway. The lowered section would have an elevation of 2141.0 feet, 0.5 feet above the invert of the existing spillway pipe. Ideally, this area would be in native soil and would require only minor erosion protection. This option would allow the lake level to remain at its current elevation. Figure 7 provides a conceptual drawing of this repair scheme.

Option 2: Reduce Lake Level, add 45 foot wide emergency spillway – This option would involve retaining the existing dam crest elevation, restoring the drop-inlet or lowering the 36-inch CMP to maintain normal lake elevation at 2139.5 feet, and lowering a 45 foot wide section of the dam crest to 2140.0 feet to act as an emergency spillway. Figure 8 provides a conceptual drawing of this option.

Whichever of the options is chosen, detailed plans for the selected repair scheme will have to be prepared by a professional engineer and approved by the DSO prior to construction.

5.2 Operation and Maintenance Plan

An Operation and Maintenance Plan must be prepared for Serenity Dam. As a minimum, the O&M Plan should include:

- A listing of procedures involved in operation of the dam, and the person(s) responsible for performing them.
- Procedures for the owner to conduct monthly and annual inspections of the dams.
- Routine maintenance activities that must be performed regularly, such as grass and brush trimming, debris removal from the spillway, and repair of animal burrows.

- Routine monitoring and recording of seepage flows.

Additional information to assist in developing the O&M Plan is contained in Ecology Publication No. 92-21, *Guidelines for Developing Dam Operation and Maintenance Manuals.* The Simplified O&M Plan Form can be used in lieu of completing a lengthy manual from scratch. This plan must be submitted to the DSO within 180 days following issuance of this report, as required in WAC 173-175-510.

5.3 Emergency Action Plan

An Emergency Action Plan needs to be written for Serenity Dam to meet current DSO requirements. The EAP should include the following:

- Notification procedures (preferably in the form of a flow chart) and responsibilities for notifying downstream residents in case of an impending dam failure.
- A notification list that includes the names and telephone numbers of local emergency officials and appropriate government agencies (including the Dam Safety Office).
- A clear description of situations where the need for warning should be issued. Such situations would include excessive, cloudy or muddy seepage; embankment slumps, or depressions forming on the slopes.
- Specific instructions for the owner to be followed at the dam site in response to emergencies such as heavy rains, equipment failures, or other unusual events where the situation is evolving slow enough that immediate remedial action can be effective to prevent failure.
- Procedures to follow for emergency situations that probably would not lead to dam failure, but still could represent a hazard for downstream residents.
- Dam breach inundation maps (see Figure 4).

Detailed information on preparing an Emergency Action Plan is contained in Ecology Publication 92-22, *Guidelines for Developing Dam Emergency Action Plans*. Again, this plan must be submitted to the DSO within 180 days of issuance of this report.

Appendix A - Figures

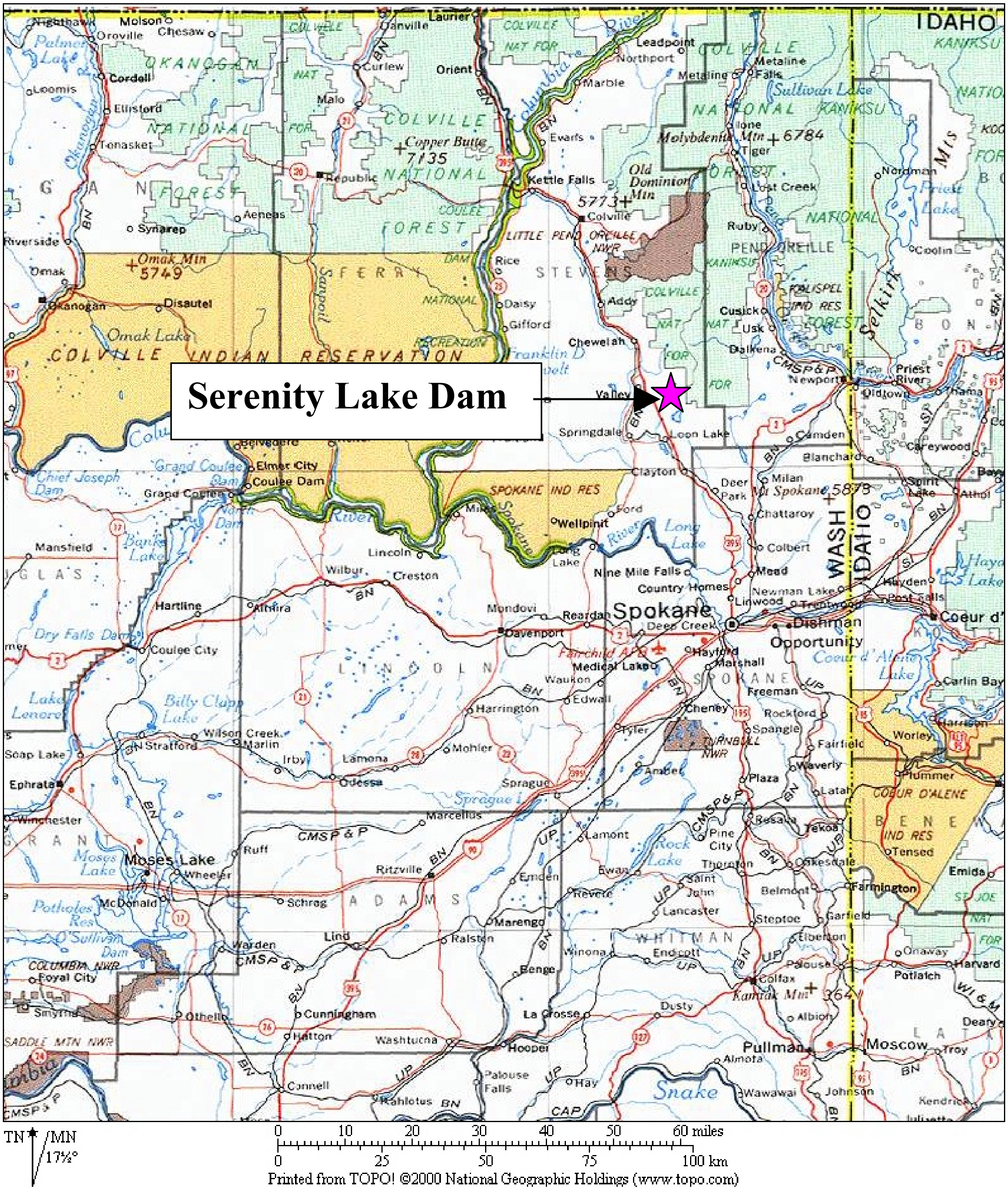


Figure 1 – Location Map

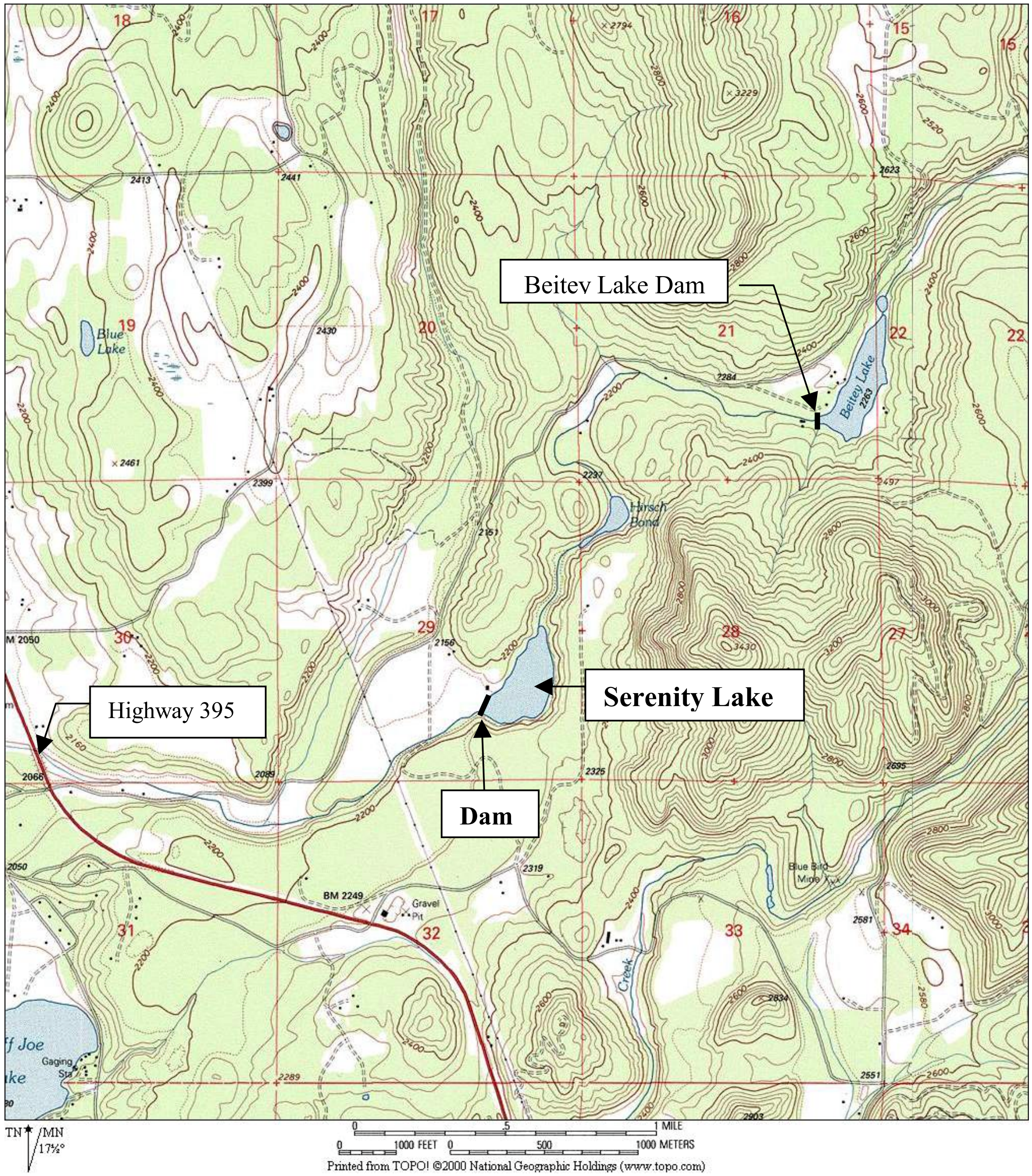


Figure 2 – Vicinity Map

Figure 3 - Serenity Lake Dam
Dam Crest Survey

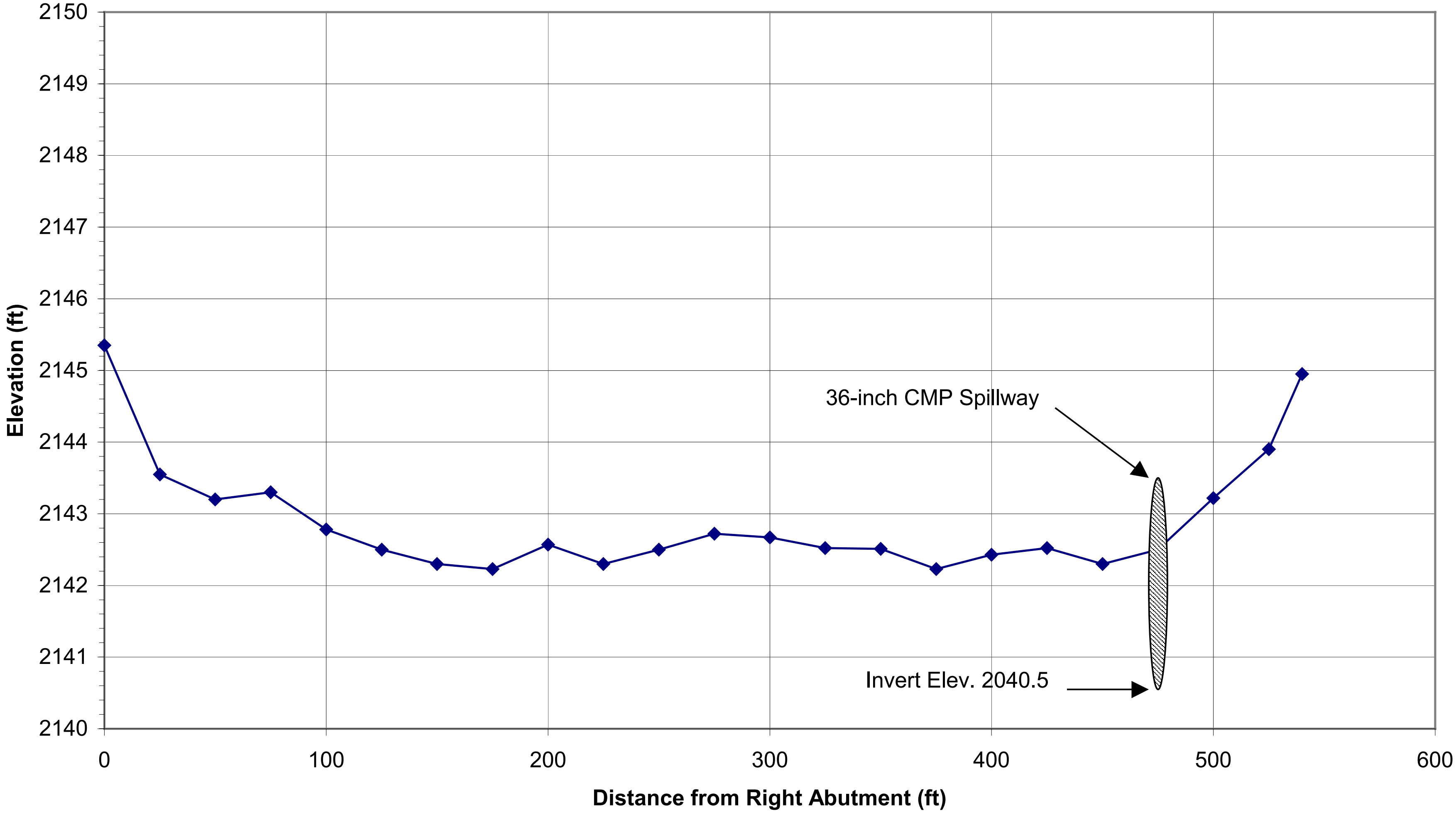
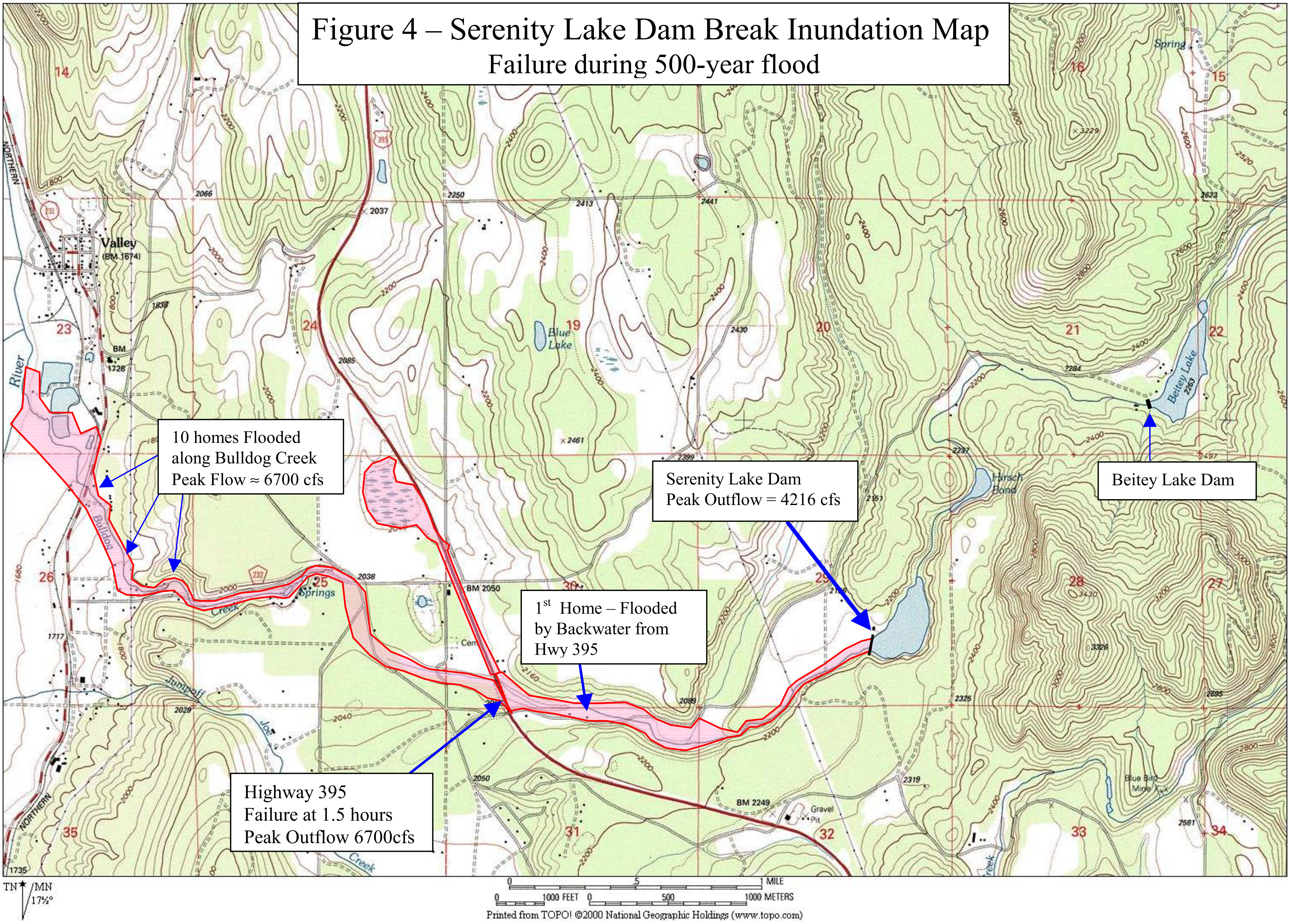


Figure 4 – Serenity Lake Dam Break Inundation Map

Failure during 500-year flood



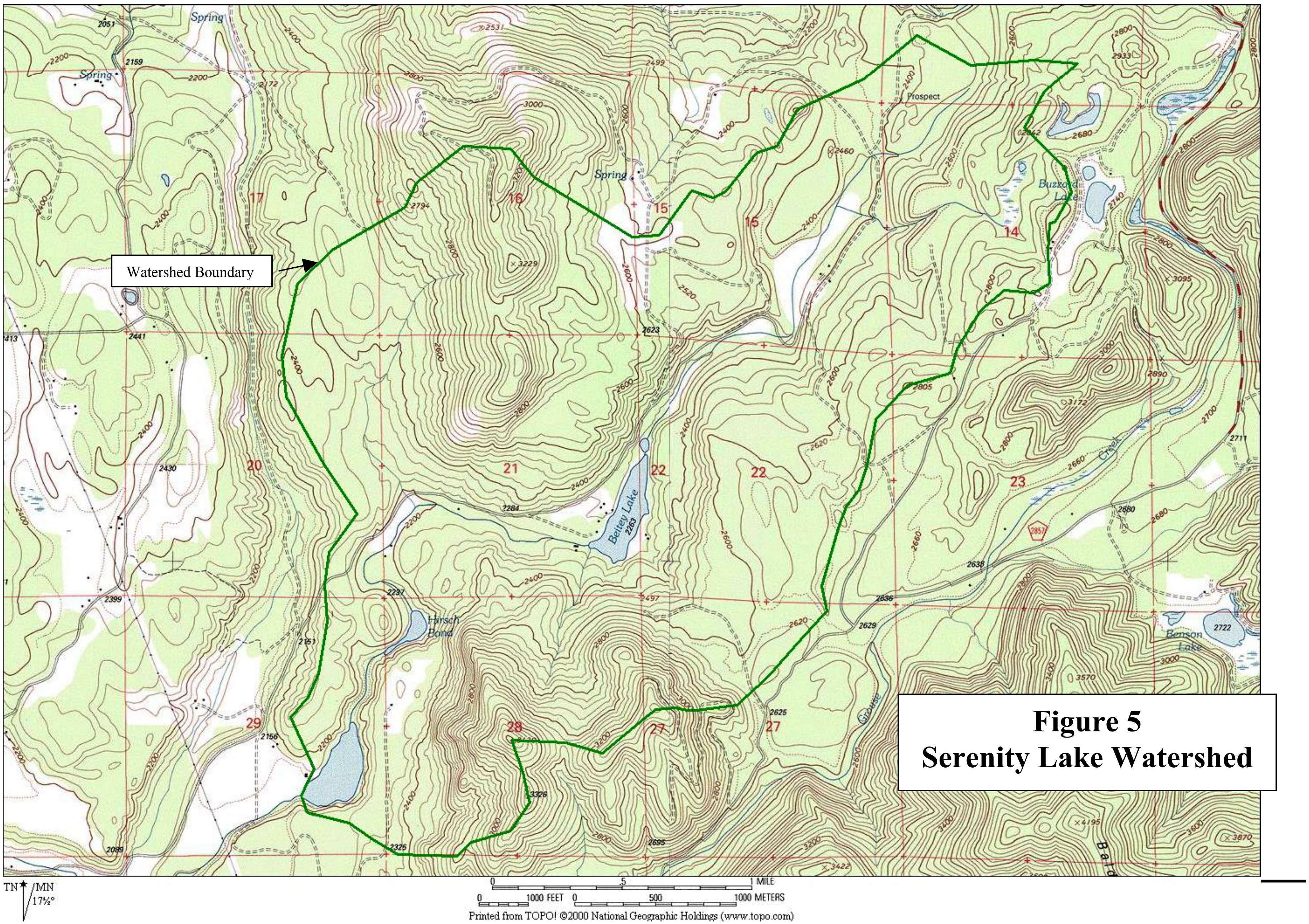


Figure 5
Serenity Lake Watershed

Figure 6 - Serenity Lake Dam
Inflow Design Flood Hydrograph

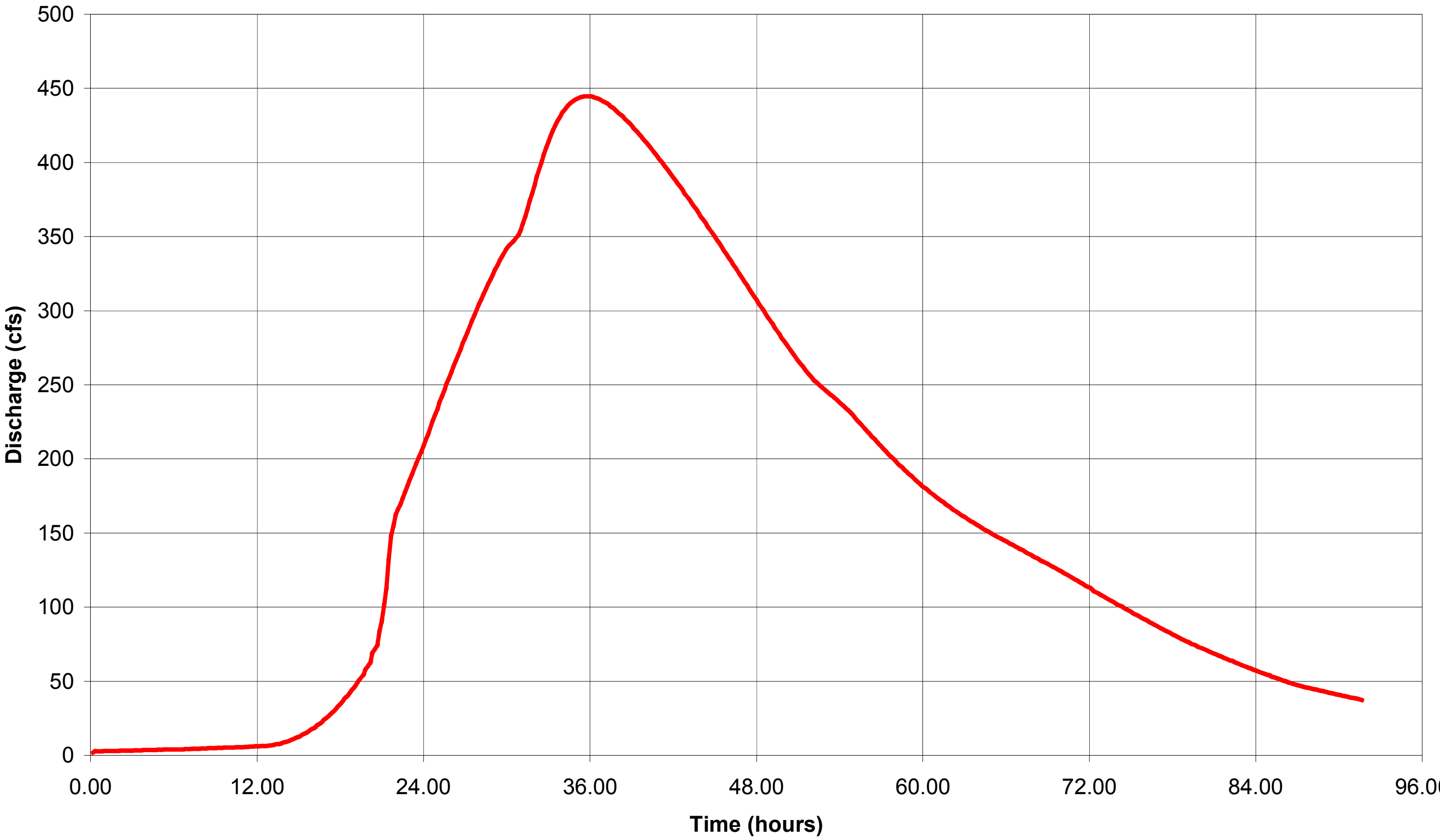


Figure 7
Serenity Lake Dam Repair Option 1

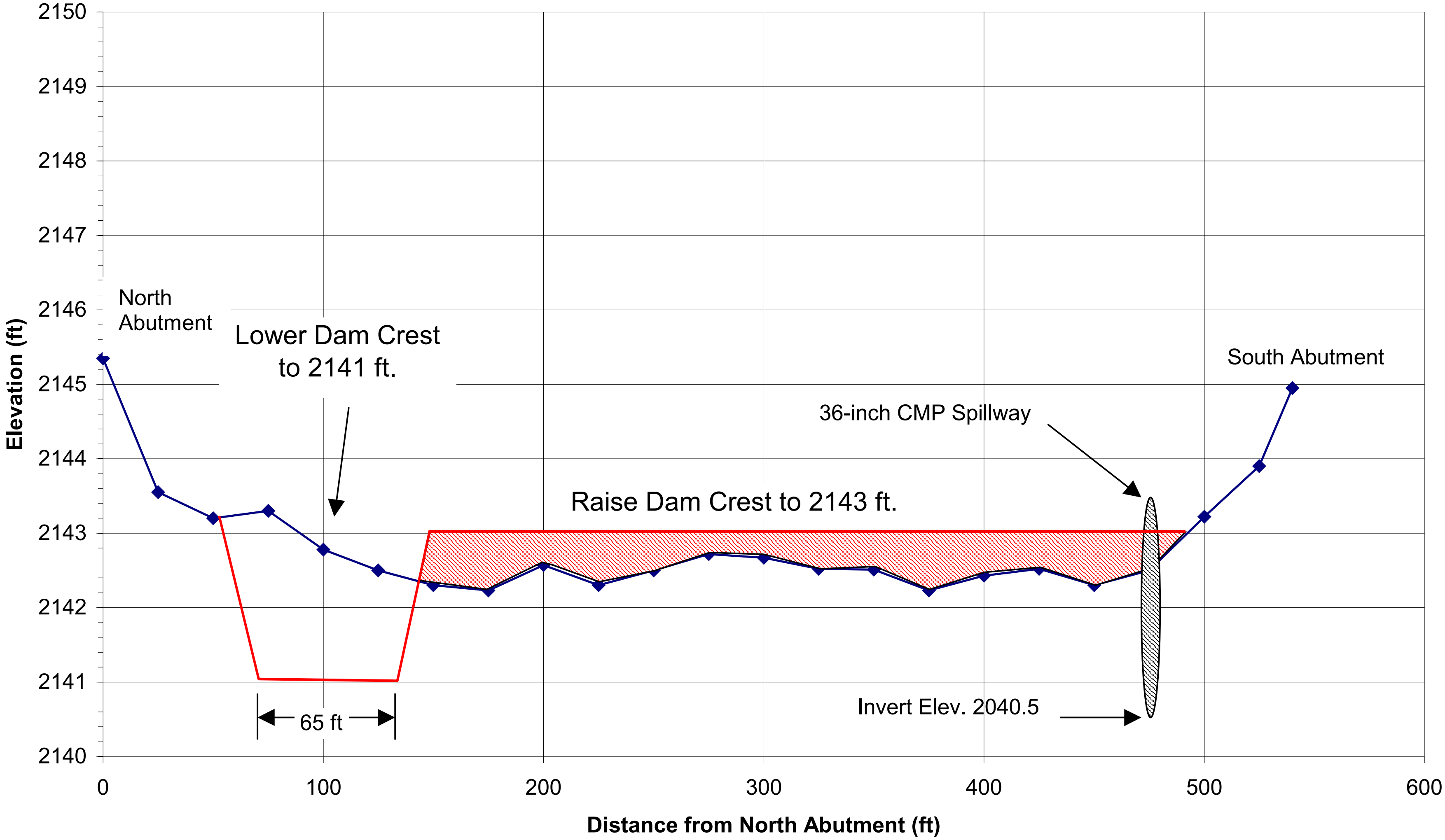
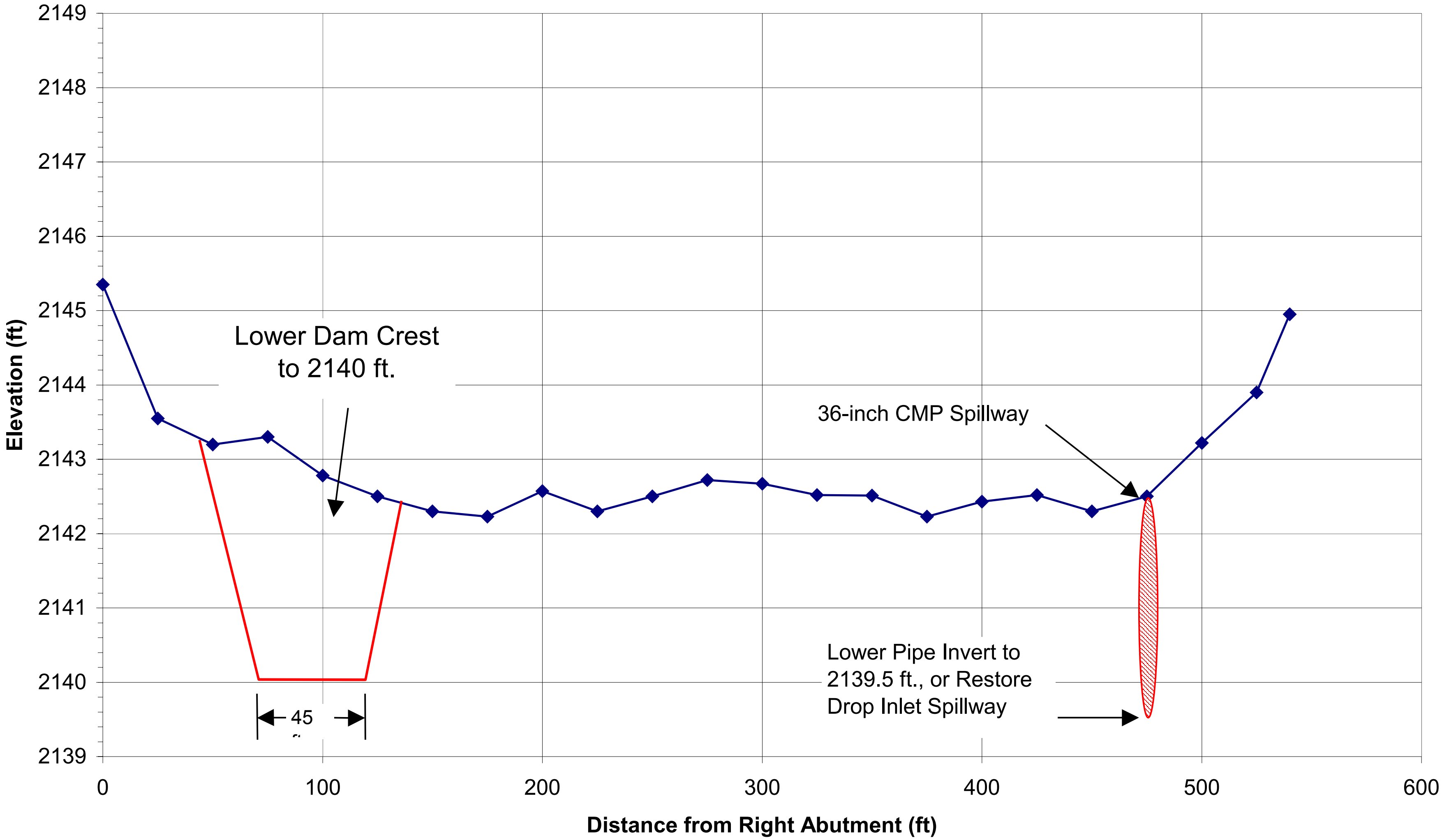


Figure 8
Serenity Lake Dam Repair Option 2



Appendix B - Photographs

Photo 1: Serenity Lake Dam Looking North

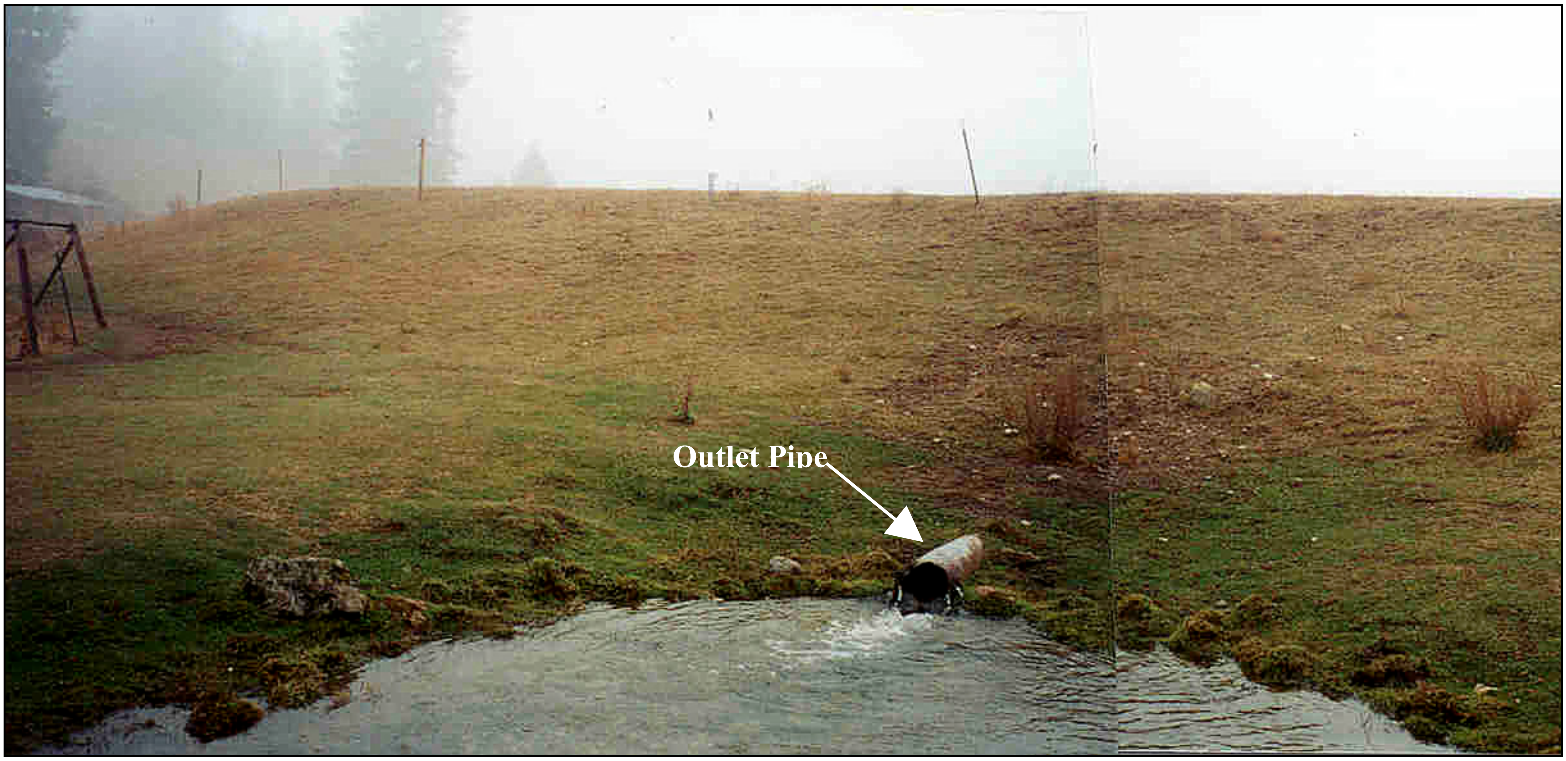


Photo 2: Downstream Face at Outlet Location

Photo 3: Downstream Face Looking South toward Spillway

Photo 4: Collapsed Animal Burrows on Crest

Photo 5: Outlet Channel Downstream From Dam

Photo 6: 36-inch CMP Spillway Conduit

Photo 7: Half-round Flume Downstream from 36-inch CMP

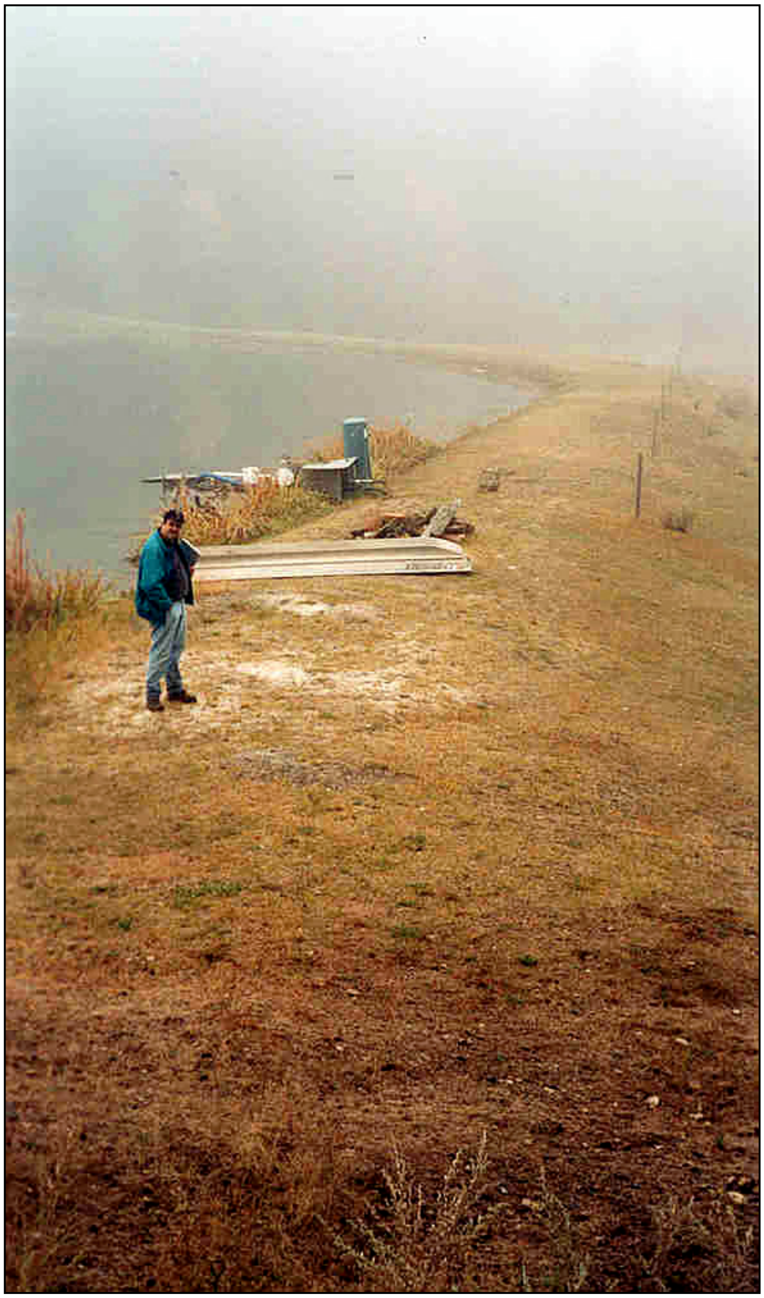
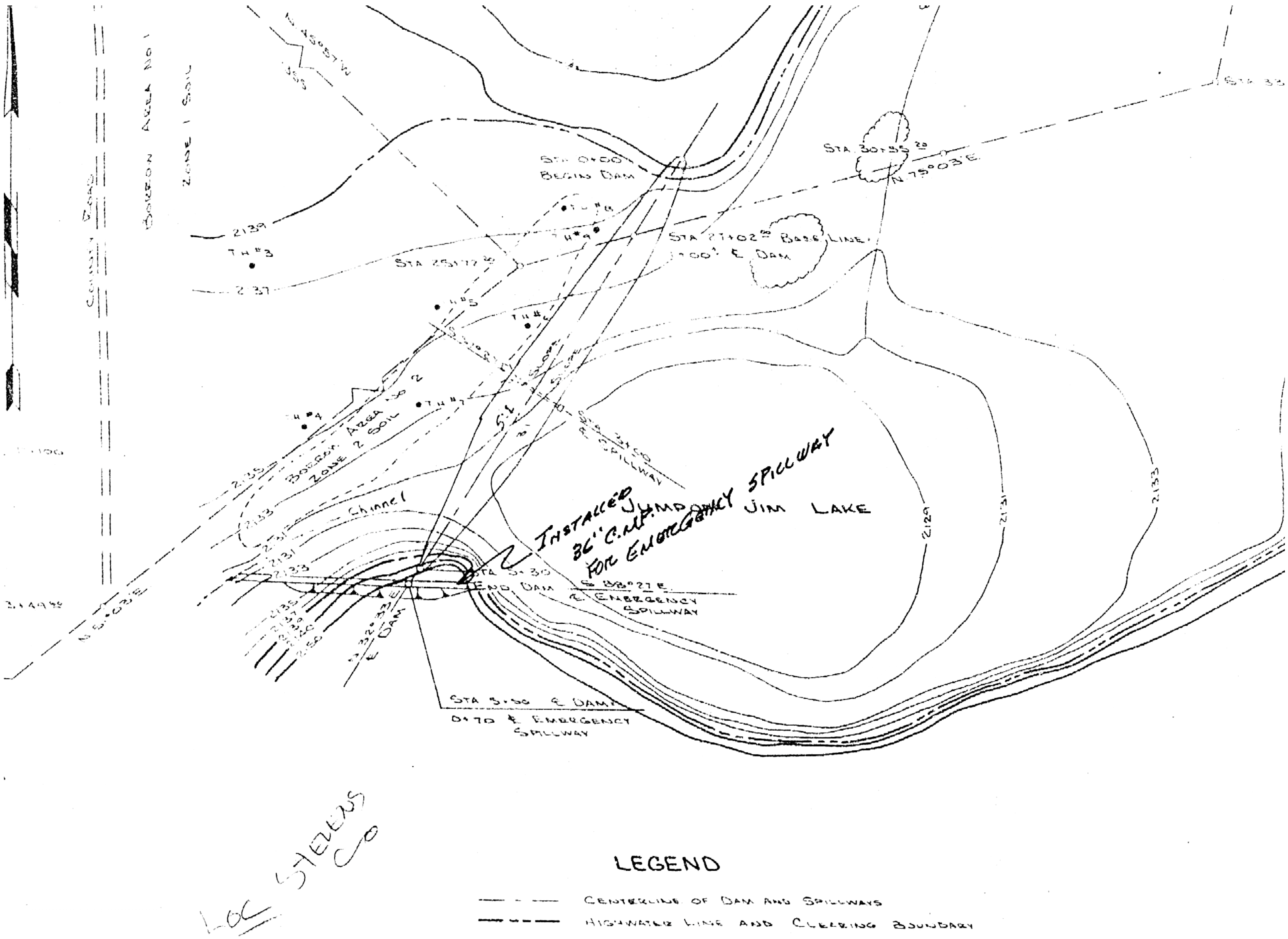
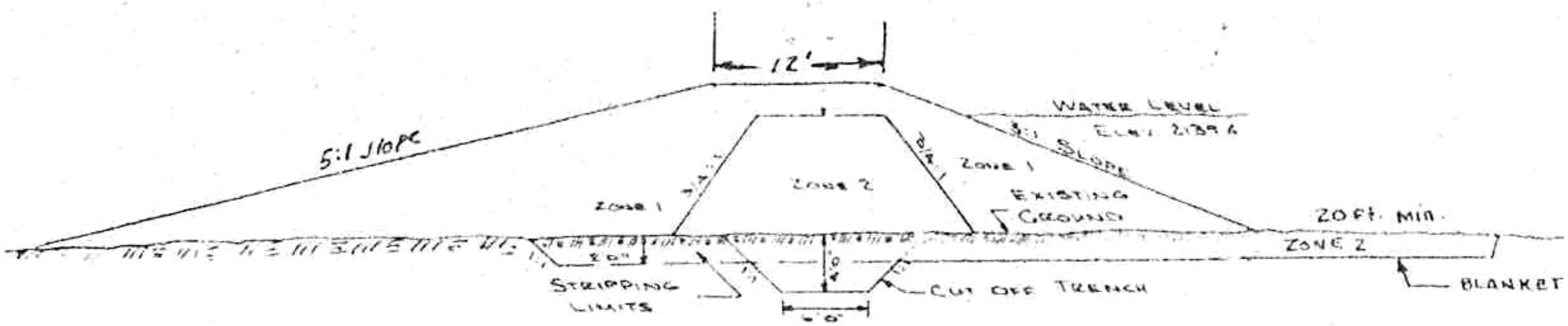


Photo 8: View of Dam from North Abutment. Person is Standing in Location of Proposed Emergency Overflow

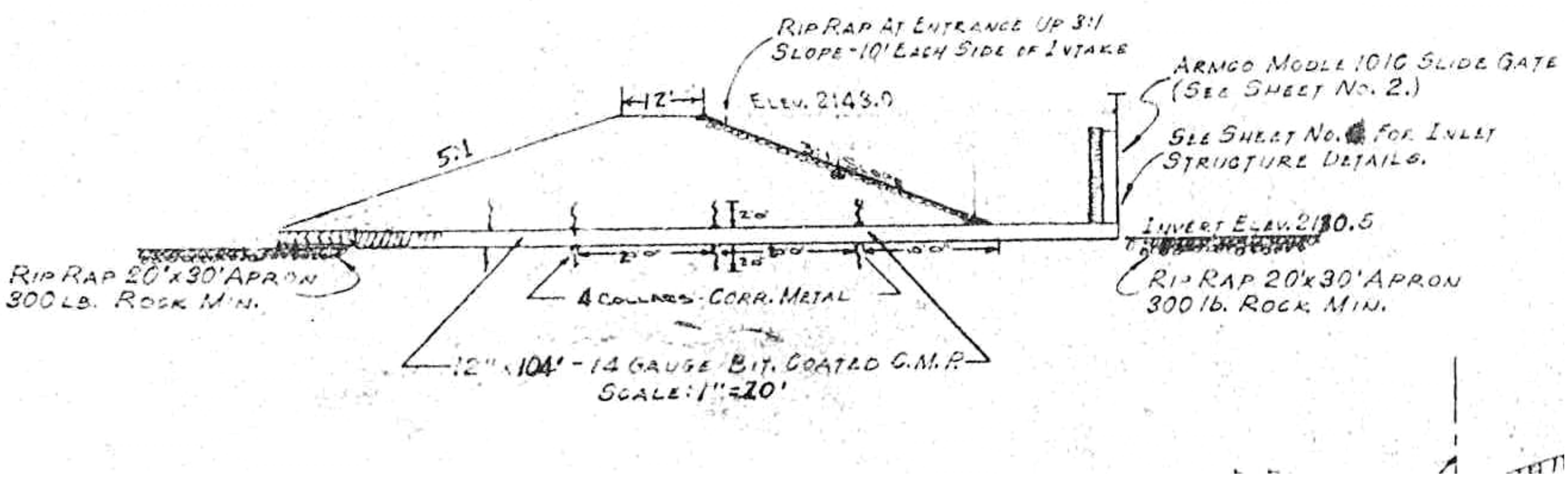
Appendix C - Drawings



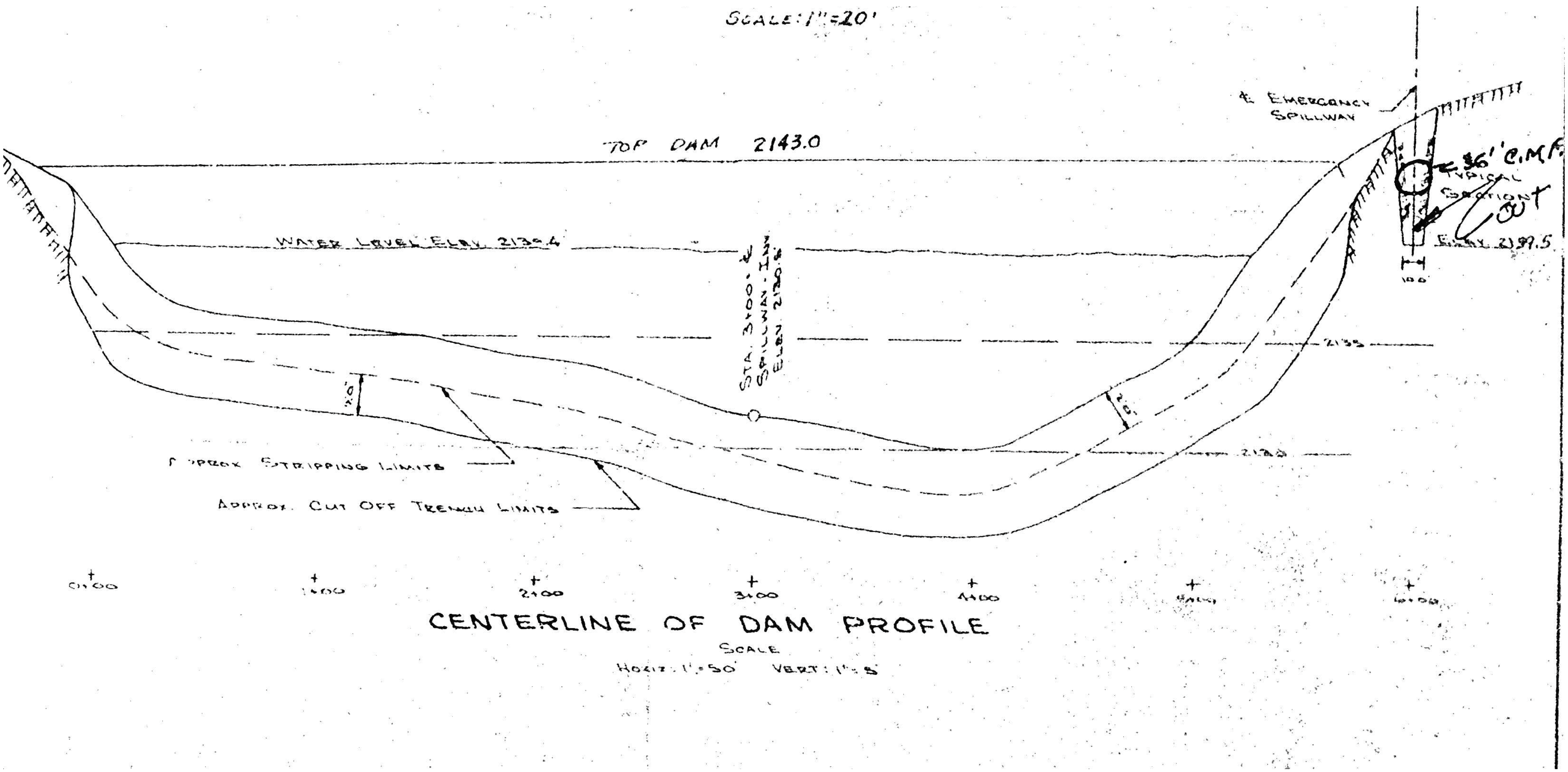
Drawing 1 – As-built Plan View of Dam & Reservoir Area



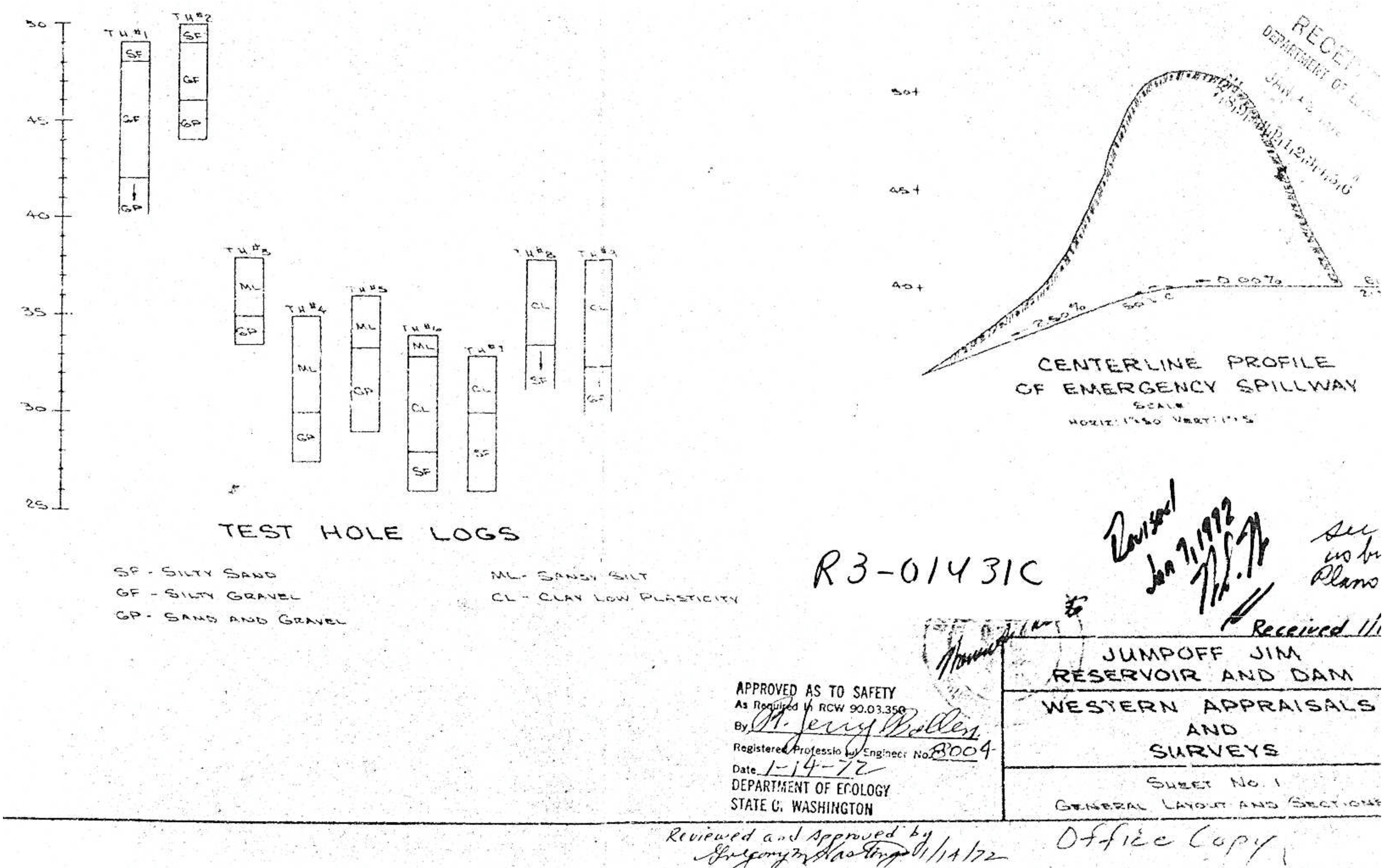
TYPICAL SECTION



Drawing 2 – Typical As-built Sections



Drawing 3 – As-built Centerline Profile of Dam



Drawing 4 – Approval Page from Original Plans

Appendix D – References

References

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